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ANIMAL MECHANICS.[1]

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Reference was made to a former lecture before the Michigan Short-horn Cattle Association, in which the relations of heredity and variation to the improvement of live stock were discussed, and attention was called to the flexibility of the constitution of domestic animals that made them susceptible to the modifying influences of the conditions in which they are placed—so that variations are constantly produced by changes in food and management, and constant care must be exercised to select the animals presenting desirable variations to fix and retain them as inherited characters.

In presenting these fundamental principles in the improvement of animals, many important details were necessarily omitted, and at the present time my purpose is to supplement the general subject of heredity and variation, by calling attention to some of the latest contributions of science to the philosophy of feeding, and notice their relations to the principles of selecting breeding stock, that are often overlooked by inexperienced breeders in their efforts to improve their animals in special qualities.

In the lecture referred to, animals were compared to machines for converting the vegetable products of the farm

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into animal products of greater value. This simile, which is often made, is of greater significance than at first sight would appear, and if breeders will keep in mind the fact that they are, in effect, providing machines for doing work in the manufacture of meat, milk, wool, muscular power, or other animal products, from the raw materials derived from the soil, the means of improvement will be more readily understood.

From this point of view the breeders of live stock should have a deep interest in the general progress of agriculture, as any improvement in crop growing must be to their advantage, from the larger supply of raw materials for the manufacture of animal products, which should increase the demand for animal machines to perform the work with the greatest economy, and at the same time turn out a finished product of a quality than can be disposed of at renumerative prices in the market.

This simile of a machine makes apparent the fallacy of the old notion that the animal that eats the least is the best for the farmer. It would certainly be a poor recommendation for a machine to say that it could work up but a small amount of raw materials. The object of the farmer is, profit, and in every department of production the aim should be to obtain the largest net return from the raw materials he has to dispose of. The more the animal machine can do of useful work, the greater its value to the farmer, if the results are obtained with the greatest economy.

Another popular error will be readily corrected by looking upon animals as machines for doing work. The notion has too generally prevailed that animals are composed simply of flesh and blood and bones, etc., and that when they are furnished with food containing the materials which enter into the composition of their tissues, it would, in some mysterious way, be converted into animal substances. This is, however, a partial or one-sided view, that does not represent the whole truth.

Farmers are constantly dealing with the forces of Nature, and a knowledge of natural laws cannot fail to aid them in their mastery. The applications of the law of the conserva-

tion of energy to animal and vegetable physiology, which have recently been made, are of great assistance in giving clear and correct notions in regard to the economy of living beings, and we learn that the materials used in the constructive processes of plants and animals are not of greater importance than the motive power required to convert them into living substances.

The law of the conservation of energy has revolutionized modern physics, and the industries have been directly benefited by its applications, and its influence in agriculture when rightly applied, can hardly be overestimated. Faraday pronounced it "the highest law in physical science which our faculties permit us to perceive," and it has been claimed to be the most important discovery of the present century.

Energy has been defined as "the power of doing work, or overcoming resistance." Its familiar manifestations we call heat, light, motion, electricity, etc. These different forms of energy are mutually convertible, without gain or loss, or, in other words, the energy of the Universe is a constant quantity that is neither increased or diminished by the transformations it undergoes.

All forms of energy may be transformed to heat, and this furnishes a convenient unit or standard for measuring it. The unit of heat is the amount required to raise one pound of water one degree in temperature. Its mechanical equivalent is 772 foot-pounds, which is the unit for measuring work. That is to say, the heat required to raise one pound of water one degree in temperature, is equivalent to the force required to raise a weight of one pound 772 feet, or a weight of 772 pounds one foot, which is, conveniently expressed, as 772 foot-pounds, the weight in pounds being multiplied into the distance in feet through which it is raised. Foot-pounds divided by 2000 will give the result in foot-tons, which is often used.

When a weight of one pound is raised 772 feet, it represents, in that position, 772 foot-pounds of potential, or stored energy, and when this weight is allowed to fall the entire distance without interruption, the stored energy is transformed into active energy or motion, and when this motion is arrested on

completion of the fall of 772 feet, heat is liberated sufficient to raise one pound of water one degree in temperature, or, the equivalent of the energy required to raise the weight to the height from which it fell. This serves to illustrate what is meant by the conservation of energy.

The transformation of food constituents into animal subtance involves the performance of work by the animal machinery of nutrition, which is carried on at the expense of the stored energy of the food consumed. An expenditure of energy in work is as necessary to convert corn or grass, into animal subtance, as in the hauling of a load on the road, and the term work is as applicable, in the same sense, in the one case as in the other. Sheep growing wool, cows giving milk, and animals fed for the butcher, should, therefore, be recognized as working animals, as well as those used in draft, or in lighter, more rapid work on the road.

Internal work must be done in the first place to convert vegetable substances into animal substance; and, in the next place, an additional amount of work must be done in the further conversion of animal substance into the special animal products of meat, milk, wool and muscular force, which are the real sources of profit in feeding. Moreover, this internal work involves the wear and tear of the animal machine, which unlike purely mechanical devices, makes its own repairs at the expense of the raw materials it is its mission to convert into animal products.

An important question here presents itself; how is the food consumed by animals disposed of, and what purpose does it serve in the animal economy? The correct answer to this is of great practical importance and interest to every farmer, and especially to breeders of improved stock.

In the first place, materials are provided for growth, and for the needed repairs of the system, but only a small proportion of the food constituents are utilized for these purposes, as will be seen from the following table giving the results of experiments at Rothamsted.

Each 100 pounds of food constituents consumed by fattening animals were disposed of as follows:

Constitutents of Food. 100 lbs. each.	Stored in increase.			Voided in Excreta.		
	Oxen.	Sheep.	Pigs.	Oxen.	Sheep.	Pigs.
	lbs	lbs	lbs	lbs	lbs	lbs
Proteids	4.1	4.2	13.5	95.9	95.8	86.5
Non-proteids	7.2	9.4	18.5	14.1	8.9	4.1
Minerals or Ash	1.9	3.1	7.3	98.0	97.0	92.7
Dry Substance	6.2	8.0	17.6	36.5	31.9	16.7

The food constituents not accounted for have served a useful purpose in their liberated energy for the performance of work, and their residues have been exhaled in the gaseous form, and the surplus energy as animal heat. Growing animals, and cows giving milk, will retain, or utilize a larger proportion of the food constituents, but even then much the larger part of the material elements of the food are discharged in the excreta.

In the next place, the potential or stored energy of the food is made available in all of the work done by the system, and it is the sole source of power in all of the processes of the animal machine.

From the prominence given to the chemical theory of nutritive ratios in some of our agricultural papers, farmers are asked to believe that success in feeding depends upon following certain theoretical formulas, giving the proportions of food constituents in the rations fed, while the animal machine which does the work of manufacturing valuable animal products, and the motive power that makes it efficient, are entirely ignored. I can only say in passing, that in the present state of knowledge, we cannot formulate the constituents of foods in chemical terms, to serve as practical guides in feeding. The machine itself, is the most important consideration, and its capacity, for doing the work required of it, is of far greater significance than the proportions of the comparatively small amount of the so-called nutritive constituents stored up, or used by the animal.

Let us for a moment consider the facts in regard to the construction and repair of other farm machinery, as reapers, mowers, threshing machines, etc. When we take an exact inventory of the items of cost, in the construction and repair of these machines, we find that the materials of which they are made, or are used in repairing them, make but a small fig-

ure in the expense account, and that the work done in shaping and fitting the materials in proper relations, represent a very large proportion of the real cost of the machine or of the repairs that may be made. In repairing a machine, a few cents may pay for the iron or wood used, while several dollars would be required to pay for the work done.

The same principle holds good with the animal machine, both in its original construction and its repairs. But a small proportion of the food constituents are utilized in the processes of nutrition, and a very large amount of energy is constantly expended in the work of transforming these materials into animal substance and animal products.

The real significance of these facts will best be seen by making a quantitative estimate of the energy expended, and the transformations it undergoes in organic processes, as represented in the following table giving an approximate statement of the composition of one acre of corn, and of a fat ox analyzed at Rothamsted.

	Constituents	Corn one Acre. 3360 lbs. grain, 3840 " stalks, 7200 lbs. total		Fat Ox. Fasted Live Weight, 1419 lbs. (Contents of Stomach, etc., 85 lbs.).	
		Per cent.	Lbs.	Per cent.	Lbs.
A	Carbon	39.7	2858	31.6	448
	Hydrogen	7.0	504	9.7	137
	Oxygen	48.8	3511	46.5	660
	Nitrogen	1.3	90	2.4	34
	Ash	3.3	237	3.9	55
	Potash	1.10	79	0.18	2.6
	Phos. Acid.	0.53	38	1.55	22
B	Water	17.1	1232	45.5	646
	Proteids	7.8	562	14.5	206
	Fat	3.3	237	30.1	427
	Carbhydrates	68.5	4932		
	Ash	3.3	237	3.9	55
	Potash	1.10	79	0.18	2.6
	Phos. Acid	0.53	38	1.55	22

Stored energy representing work done.	17,083,000 foot-tons, equivalent to the work of one horse continuously for 719 days.	3,381,000 foot-tons, equivalent to the work of one horse day and night for 142 days.

A chemical analysis of the corn shows (division A of the table), that it is composed of 2858 lbs. of carbon; 504 lbs. of hydrogen; 3511 lbs. of oxgen; 90 lbs. of nitrogen; and 237 lbs. of ash, or mineral constituents, the most important of which are potash 79 lbs., and phosphoric acid 38 lbs. The ash constituents and the nitrogen are alone derived from the soil.

We have here the elements of which the crop is composed, but division B of the table shows that they represent water 1232 lbs.; proteids 562 lbs.; carbhydrates 4932 lbs.; and ash 237 lbs. These are the facts furnished by chemistry in regard to the composition of the acre of corn, but they do not represent the whole truth.

To transform the simple elements of division A of the table into the complex organic compounds of division B, energy must be expended and work done, and the energy so used is stored up in the organic substances formed as an essential condition of their constitution. The amount of this stored energy is represented in division C of the table, and it is an important factor in the composition of the crop of corn, as it is one of the essentials in animal nutrition.

This stored energy of the corn does not, however, represent the total expenditure in the growth of the crop. Experiments show that for each pound of dry organic substance formed by the growing corn, about 300 lbs. of water will be exhaled, or thrown off by the plants in the form of vapor. To convert water into vapor involves an expenditure of energy, and this for the acre of corn would be approximately equivalent to the work of 24 horses for six months without intermission. Water is likewise evaporated from the soil as one of the essential conditions of fertility, and this calls for a further expenditure of energy, which under our climatic conditions may be estimated at about twice the amount expended in exhalation from the plants themselves. Taking all of these processes together, the

energy expended directly and indirectly in Nature's invisible unobtrusive work of growing an acre of corn, must be equivalent to the work of 76 horses, day and night, for six months.

This energy is all derived from the heat and light of the sun. The importance of proper soil conditions to favor the required transformations of energy in the growth of the crop will readily be seen.

The motive power of the animal machine, in all of its processes of nutrition and growth, is derived exclusively from the stored or potential energy of their food, and we may ask how this energy is liberated and made available in the animal economy.

As the energy used in its construction is stored up by the plant as an essential condition of its constitution, any disintegration of its organic substance will liberate the stored energy in the form of heat. This may be brought about in several ways. 1.—The plant may be burned, and the heat produced represents its stored energy. 2.—Microbes feeding on organic substances tear them apart and liberate the stored energy in the form of heat. The heat produced in the familiar processes of fermentation and putrefaction, all of which are caused by microbes, is but the stored energy of the organic substances on which they feed. 3.—The digestive processes of animals involve a disintegration of the food constituents, and liberate their potential energy for use in the processes of animal nutrition.

Turning now to the table, for the composition of the fat ox, we find it represented in division A, as consisting of simple elements, and in division B the complex compounds built up from these elements are given. It will be seen that work has been done, and energy expended in transforming the simple elements of division A into the complex compounds of division B, and, as in the case of the corn, the estimated amount of this expenditure of energy is given in foot-tons, and horse power, in division C of the table.

The popular notion that the proteids, fat and carbhydrates of the corn are directly converted into the proteids and fat of the ox that eats them, (division B), does not take into account

all of the factors concerned. We have seen that energy must be expended in work to convert vegetable substances into animal substances, and this energy can only be obtained by tearing apart the vegetable compounds through the processes of digestion, and liberating their stored energy. In this process the vegetable compounds of the food are resolved almost into their elements, and from these comparatively simple substances by means of the energy liberated, the proteids and fats of the ox are manufactured.

The complex animal substances thus formed are continually undergoing change. The wear and tear of the animal machine involves a disintegration of its organic substance, and its stored energy is liberated as heat. This may in part be used again in the processes of repair, but a large proportion leaves the body as animal heat.

As in the case of the corn, the stored energy (division C of the table), of the fat ox does not represent all of the energy expended in building up its organic substance. A constant process of repair has been going on to replace the waste resulting from the wear and tear of the system, which involves a continuous expenditure of energy—and the loss arising from the energy thrown off from the body as animal heat, (radiation), and expended in vaporizing the water exhaled from the skin, (perspiration), must be replaced at the expense of the stored energy of the food to keep the machinery of nutrition, in efficient activity.

The facts presented are sufficient to show that the transformations of energy are important factors in the economy of plants and animals, and that the materials of which they are composed cannot be looked upon as the sole subjects of interest in farm economy. The tendency to make the compounding of food rations the prominent subject for consideration, conflicts with the interests of the breeders of improved stock, and misleads the farmers who are induced to look upon it as the real source of profit. This reference to the subject of feeding is made with the two-fold purpose of calling attention to the fallacy of feeding experiments in which the chemical composition of foods is made the prominent or sole object of interest,

while the importance of the improvement of the live stock of the farm is wholly ignored; and to remind breeders that they are fully warranted in claiming that improved animals are entitled to the first place among the means of an improved agriculture, as machines for manufacturing the crops grown on the farm into marketable products.

The most serious obstacles to the progress of agriculture at the present time arise from the one-sided and misleading statements that are made in the name of science by those who have but a superficial knowledge of Nature's laws, and their intimate relations to farm practice. The experiment station reports, on the feeding of animals, fail to give a full statement of all of the factors that may influence the results, and too often the record is made to conform to hasty assumptions, or false theories, so that it is difficult to find a grain of truth in the mass of chaff that is scattered broadcast over the country.

As the remarkable progress made in other productive industries has been largely owing to improvements in machinery, so progress in agriculture must depend, to a great extent at least, upon the further improvement of the animal machines that are so essential to success in the business of farming, and we must look to the breeders of the pure breeds to accomplish this desirable object.

It will not answer to rest satisfied with the present high development of the pure breeds and their more general diffusion on the farms of the country, but the aim of every intelligent breeder must be to still further increase their useful qualities in special directions. Notwithstanding the decided superiority of the pure breeds over the average farm stock, there is still a wide margin for improvement, as there are good reasons for believing that even the best animals do not utilize more than one-half of the available energy of their food in useful work.

The largest profit can only be realized with animals that have the ability to consume and utilize in useful work, an amount of food considerably in excess of what is required in the needed repairs of the system. This involves severe work,

and one of the first essentials to be considered is that of stamina and constitution, or, in other words, the capacity for hard work and powers of endurance, or the same qualities in this respect that all working animals should possess.

These qualities are largely determined by heredity, and selections for breeding purposes should be made with reference to these qualities in the ancestors. Good sanitary conditions must of course be maintained, to secure a continuance of robust health and an active performance of the normal functions of nutrition.

Prepotency.

Strength of constitution or powers of endurance must not be confounded with prepotency, or the quality of holding a preponderating influence in the act of reproduction. Many animals that are prepotent in transmitting their own qualities, are deficient in constitution, and their offspring lack that active and vigorous performance of the nutritive organs that is essential to stamina and powers of endurance in useful work. Prepotency arises from uniformity in the characteristics of ancestors for many generations, and these characters may or may not be desirable.

In the improvement of the pure breeds with their present high development of valuable qualities, an accumulation of slight variations must be the aim. We cannot expect to gain any wide departure from present characters at a single step. Progress can only be made by a succession of short steps, and their sum will represent the real advantage gained. Small items determine the difference between gain and loss in the present activity of the industries, and in agriculture we must recognize the importance of slight improvements in each detail of general management as the only available method of making real progress.

Breeding to a Type.

In making selections for breeding, an ideal type of excellence representing definite valuable qualities, should be strictly

adhered to. This type, in all cases, should represent the highest development of characters that indicate the posession of the desired useful qualities. The form should be that which represents a special adaptation to the particular purpose in view. It is well known that the general form of animals is correlated with particular functions. The form of the roadster differs from that which is suited for heavy draft, and the type for rapid meat production is different from that giving the best results in the production of milk.

The law of correlation has, however, a further application. There is not only an adaptation of the general form to the kind of work that can best be done, but the different organs of the body have correlated relations that are quite as significant. An excessive activity, or development of one organ, or set of organs, diminishes the activity or development of the system in other directions. That is to say, the system has a capacity for utilizing a certain amount of energy, and if it is largely expended in one direction there is less to be expended for other purposes. If the tendency to lay on fat predominates, the milk producing functions must suffer a corresponding diminution, and severe muscular work will diminish the tendency to lay on fat, or produce milk.

To give permanency and uniformity to the ideal type that has been adopted, selections for breeding must be strictly confined to animals having the desired characters, within the limits of a distinct breed, or of a single family of a distinct breed. This is in effect establishing, or fixing, family characters in the particular breed. The constitution or physical stamina of the family type should not be lost sight of in attempts to secure other desirable characters, as on it will depend the efficiency and profitable exercise of the special functions that have been cultivated and fixed as family characters.

All coarseness should be avoided. Improvements in all breeds have been made by securing a greater refinement of the system, or in diminishing the proportion of coarse parts. Large bones, with apparent good reason, have been looked upon as an indication of imperfect nutrition, and as a general

rule, to which there are few, if any exceptions, they are correlated with coarseness in other parts. The wear and tear of the animal machine is greater in such cases, and a larger expenditure of energy is required in its repairs.

INHERITED HABITS.

Aside from the general inherited habits of animals with which you are all familiar, as the tendency to early maturity, or the habit of milk production throughout the year, or in what is called the trotting instinct, there are inherited habits of the nutritive organs themselves which should not be overlooked.

Habits are cultivated and established by their systematic exercise, and the desirable habits of the nutritive organs can only be cultivated and maintained by their constant exercise, or, in other words, by liberal feeding, and the direction in which the liberated energy of the food is expended must, at the same time, be determined and promoted by cultivating the general and special habits of the system. If, for example, milk is a leading object, in connection with a liberal supply of food, from which energy is freely liberated through the inherited activity of the nutritive organs—a sufficient capacity of the udder and other organs concerned in milk production must be provided—and a dominant tendency to the expenditure of the available energy in the milk producing function must be kept up by gentle treatment and regularity in milking and feeding. Judgment and skill must be exercised and attention given to many details, all tending in the same direction, to give the desired bias to the energies of the system.

The application of general principles will be found a better guide in practice than any specific empirical rules, and the habits of the system developed by judicious exercise and cultivation, must be fixed by systematic selection as hereditary characters.

GENERAL PURPOSE ANIMALS.

We can only call attention to some of the principles already presented to illustrate this special subject. There is, undoubt-

edly, a greater difficulty in securing two qualities on a high plane of excellence, than to obtain an extraordinary performance in a single special direction.

Milk and meat production are not strictly incompatable, and a high degree of excellence may doubtless be obtained with both. Greater skill is, however, required to combine the two qualities and retain them for any time, than to obtain a high development of either of them alone. A certain balance, or equilibrium, in the expenditure of energy, must be secured in the general purpose animal, or there will be a tendency for some single quality to predominate.

A tendency to the expenditure of energy in one direction during the period of growth, and in another direction when maturity is reached, may be cultivated and fixed by heredity. This principle is an important one for consideration in breeding dairy stock. When a cow is giving milk the tendency, or inherited habit of the organs of nutrition, may be to expend the entire energies of the system in the milk producing function, and when she becomes "dry," the available energy may be expended in laying on fat. The difficulty is, however, to maintain a due balance of the two functions. If the fattening tendency predominates, the period of giving milk may be shortened and the activity of the function ultimately diminished. One of the best precautions against this is to retain in perfection the milking type in the general form of the animal, and to keep up the milk secreting function as long as possible by proper management. Constant care in the selection and treatment of the animals will be required to secure the most desirable balance between the two functions, and prevent a predominance of either.

Exercise as a Factor in Improvement.

From the general principles already noticed, it must be seen that the exereise of special organs, and of the general system, are necessary to secure the highest excellence in the working of the animal machine. We must keep in mind the fact that the exercise of an organ or group of organs, involves an expenditure of energy, and what is spent in one direction can-

not be used in another, that is to say, that work performed by one organ diminishes the amount of energy to be expended in work by another. Judgment is, therefore, required to adopt the exercise, in a particular case, to the requirements of the system for a special purpose.

The general exercise of the muscular system is undoubtedly desirable in growing animals to secure the symmetrical development of all organs, or parts of the body. Even in the process of growth a bias, or tendency to the expenditure of energy in a particular direction may be encouraged. This is illustrated in the Palo Alto training of youngsters. Culture and heredity have given the remarkable development of the trotting horse, and early culture, or training, is now looked upon as one of the most encouraging factors in future improvement.

In the animal raised for meat production, early maturity is essential, and the tendency to flesh forming may be encouraged from birth. Exercise of the general system in the early stages of growth should tend to promote the development of muscle, or lean meat, and check the tendency to excessive fat production.

While recognizing the advantages of muscular exercise during growth, in promoting the formation of lean flesh, and a symmetrical development of the system as a whole, we must not overlook its unfavorable influence under other conditions. In the case of a cow giving milk, or in that of a fattening animal, muscular exercise must result in a diversion of energy from the work of milk production or flesh formation. Any considerable amount of muscular exercise by a cow giving milk must tend to diminish both the quantity and quality of the milk produced, or at least diminish the total amount of the solid constituents of the product.

Quality of Milk and Energy.

A large mess of milk may be produced with but a small quantity of solids, and a corresponding small expenditure of energy. The best milk contains very much more potential energy than poor milk, and it must cost a corresponding expenditure of energy to produce it. In other words, more

work is done by the animal machine in making good milk than in turning out an inferior article containing a larger proportion of water.

Sex Influencing the Transmission of Hereditary Characters.

From the manner in which pedigrees are recorded in some of the herd books, there is a tendency to overlook the characteristics of the female ancestors, which, especially in the dairy breeds, are of great importance. In the chapters on "atavism," and "the relative influence of parents" in my "Stock Breeding," a number of cases are collected showing that sex has an influence on the transmission of characters. A sexual alternation in the inheritance of dominant characters is often observed, female peculiarities being more strongly transmitted to male offspring, which they in turn impress upon their female offspring; and male characters are in the same way transmitted by females. This should not be overlooked in breeding dairy stock, as the milking qualities of the grand dam frequently appear to be transmitted to her grand daughters with greater intensity, and certainty, by her sons than by her daughters. The female ancestors of the bull in a dairy herd must, therefore, be of especial interest in his pedigree, as an index of the qualities he will be likely to transmit as dominant characters to his daughters.

The means of improving animals in useful qualities may be expressed in a few general principles, and the success of the breeder will depend upon their judicious application under the circumstances presented in each particular case, and every detail of practice must conform to them to secure the best results.

The most valuable qualities of our domestic animals are the outcome of highly artificial characters, representing a wide departure from the original stocks from which they sprung; and if the same artificial conditions that produced them are not maintained, and the selection of breeding stock is not limited to the animals that have the desired characters, they are

readily impaired and finally lost. The old race characters, under careless management, have an advantage over the more unstable acquired characters that give the animal its greatest value.

Pedigrees must be studied to ascertain whether all ancestors have had the desired qualities. Cross breeding, in the widest sense of breeding together animals of distinct breeds, would not now be defended by any intelligent breeder, but the same principle is frequently acted upon in breeding together different families of the same breed, and unless there is a strong prepotency on the one side, the advantages of such crossing must be at least problematical.

Uniformity in hereditary characters, so far as we know, can only be secured by breeding together animals having the same characteristics.

The whole matter of successful breeding may be summed up in the two words "culture" and "heredity," and in the selection of breeding stock it is desirable that all ancestors should have had the required form of culture, or training, in order to secure uniformity in hereditary characters.